

Behavioural responses of male killer whales to a ‘leapfrogging’ vessel

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ABSTRACT

The research and whalewatching communities of Johnstone Strait, British Columbia, Canada have worked closely together to identify whalewatching practices that minimise disturbance to northern resident killer whales. Local guidelines request that boaters approach whales no closer than 100m. Additionally, boaters are requested not to speed up when close to whales in order to place their boat in a whale’s predicted path: a practice known as ‘leapfrogging’. A land-based study was designed to test for behavioural responses of killer whales to an experimental vessel that leapfrogged a whale’s predicted path at distances greater than 100m. Ten male killer whales were repeatedly approached and the animals responded on average by adopting paths that were significantly less smooth and less straight than during preceding, control conditions. This adoption of a less ‘predictable’ path is consistent with animals attempting to evade the approaching boat, which may have negative energetic consequences for killer whales. The results support local consensus that leapfrogging is a disruptive style of whalewatching, and should be discouraged. Similarly, as the experimental boat increased speed to overtake the whale’s path, the source level of engine noise increased by 14dB. Assuming a standard spherical transmission loss model, the fast-moving boat would need to be 500m from the whale for the received sound level to be the same as that received from a slow-moving boat at 100m. Whalewatching guidelines should therefore encourage boaters to slow down around whales, and not to resume full speed while whales are within 500m.

KEYWORDS: KILLER WHALE; WHALEWATCHING; BEHAVIOUR; DISTURBANCE; REGULATIONS

INTRODUCTION

In 1993, the International Whaling Commission resolved ‘to encourage the further development of whalewatching as a sustainable use of cetacean resources’ (IWC, 1994). Tourism based on whalewatching has become a vital component of the economies of many coastal communities and shows potential to assist many more (Hoyt, 1997). Such tourism also affects attitudes toward protecting critical whale habitat and threatened populations (Barstow, 1986; Duffus and Dearden, 1993). However, a growing number of studies link vessel traffic with behavioural changes of whales, which may lead to increased energetic costs (Au and Green, 2001; Erbe, 2002; Williams *et al.*, 2002). As a result, resource managers must now consider a potential trade-off between economic and educational benefits of whalewatching and the habitat needs of whales.

Researchers have identified four distinct populations of killer whales (*Orcinus orca*) on the coast of British Columbia (BC), Canada. Despite having overlapping ranges, each population is socially and ecologically isolated (Ford *et al.*, 2000). Whalewatching operators in this region tend to focus on the northern and southern communities of resident killer whales (the fish-eating type), since these whales are found more reliably than ‘offshores’ or the marine-mammal-eating transients. A core summer area for northern resident killer whales and whalewatching activity is Johnstone Strait, off northeastern Vancouver Island, BC. Northern resident killer whales return here each year to socialise and to feed on migrating salmon (Nichol and Shackleton, 1996). A similar core whale and whalewatching area for southern residents is in Haro Strait between British

Columbia and Washington State (Hoelzel, 1993), where proximity to urban areas makes whalewatching a much larger industry than in Johnstone Strait.

The first whalewatching company to focus on killer whales began operation in 1980 in Johnstone Strait. The whalewatching and research communities of Johnstone Strait work together closely to identify whalewatching practices that minimise disturbance to whales. Local guidelines request that boaters parallel whales no closer than 100m; approach animals slowly, from the side; and not place boats in the path of a whale – a practice referred to in the guidelines as ‘leapfrogging’. Leapfrogging is a way of achieving a closest approach to a whale that is substantially closer than 100m. It complies with the letter of the distance guideline, but not its spirit.

In 1995 and 1996, Williams *et al.* (2002) experimentally approached killer whales to test the biological significance of the 100m parallel guideline. Results showed that killer whales used a suite of subtle tactics to evade a boat even at that distance, and that these avoidance patterns became more pronounced as boats approached closer (Williams *et al.*, 2002). Some boaters see leapfrogging as a benign means of getting close to whales without violating the 100m guideline. This has the added advantage from the tourists’ perspective of making it seem that whales are approaching the boat, which is the only way for boaters to watch whales closely without violating local guidelines. Other community members view leapfrogging as a potentially disruptive style of whalewatching.

It is of concern that leapfrogging may be at least as disruptive as parallel approaches. When speeding up to leapfrog, boat noise generally becomes more intense and

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higher in frequency (Richardson *et al.*, 1995), which offers greater potential to mask killer whale communication (Bain and Dahlheim, 1994) than slower, parallel approaches. Leapfrogging involves paralleling whales for some distance, at a faster speed than that of the whale, and then turning 90° to place the boat in the whale's predicted path. At this point, the leapfrogging manoeuvre places the noise source directly ahead of the whale, which is the position where masking effects may be greatest (Bain and Dahlheim, 1994).

Effective whalewatching guidelines must be biologically relevant and local communities in Johnstone Strait have endorsed a policy of experimental testing of various components of the guidelines. Northern resident killer whales generally adopted a more erratic surfacing pattern when an experimental vessel attempted to travel in parallel with them at 100m (Williams *et al.*, 2002). It was hypothesised that whales might respond to more intense whalewatching pressure by varying the duration of dives (vertical avoidance), or by swimming faster or altering the direction of swimming (horizontal avoidance). Whales might also display surface-active behaviours, such as slapping flukes or pectoral fins on the surface of the water. A more extensive study would be required to determine whether leapfrogging elicits stronger behavioural responses than other forms of whalewatching. Since commercial operators have agreed that leapfrogging is an inappropriate style of whalewatching, it should be necessary only to demonstrate that the technique is sufficiently disturbing to justify requesting that non-commercial whalewatchers also avoid leapfrogging.

This paper investigates whether a vessel that speeds up to leapfrog a whale's path, at a distance greater than 100m, alters the behaviour of northern resident killer whales that summer in Johnstone Strait.

MATERIALS AND METHODS

Study area

Data were collected between 28 July and 10 September 1998, from a land-based observation site on the south shore of West Cracroft Island in Johnstone Strait, British Columbia (50°30'N, 126°30'W; Fig. 1). Data were collected using an electronic theodolite (*Pentax* ETH-10D with a precision of ± 10 seconds of arc) connected to a laptop computer equipped with custom software (THEOPROG; available from D.E. Bain). Cliff height and reliability of distance measurements were made using methods described by Davis *et al.* (1981) and Williams *et al.* (2002). The theodolite was located approximately 50m above mean sea level. The theodolite-computer apparatus measured the length of a 30m rope to be 28.93m ($n=20$, SE=0.18) at a distance of 3.79km. This translates to a measurement error of approximately 3.5% in terms of accuracy and < 1% in terms of precision. Percent errors in measuring cliff height, distance travelled and speed tend to be approximately equal (Würsig *et al.*, 1991).

Selection of focal animals

Northern resident killer whales enter the study area in social units referred to as matriline (Ford *et al.*, 2000). Matriline are generally dispersed with individuals spaced a few hundred metres apart, which is typical while foraging, the most commonly observed activity of resident killer whales in summer in Johnstone Strait (Nichol and Shackleton, 1996). Focal animals that could be re-sighted consistently were chosen. A focal animal typically had a distinctive dorsal fin and saddle patch (Bigg *et al.*, 1990). Only mature and

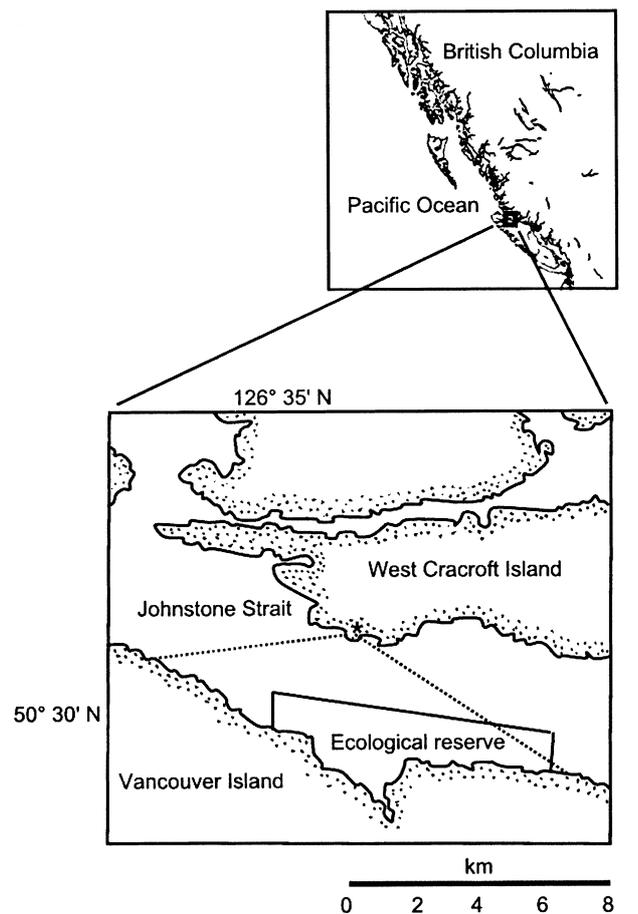


Fig. 1. Study area in Johnstone Strait, BC, Canada, showing lines of sight (.....), position of theodolite (*) and boundaries of Robson Bight – Michael Bigg Ecological Reserve.

subadult males were tracked in this study – they can be readily distinguished from other group members since their dorsal fins can reach twice the height of those of adult females. Animals were selected whose location within the study area made them likely to be visible for more than 15 minutes; earlier work has shown that tracks that are substantially shorter than 1,000s tend to bias estimates of respiration rate (Kriete, 1995).

Tracking

The tracking team consisted of a spotter, a theodolite operator and a computer operator. The spotter announced each time that a focal animal surfaced to breathe or display surface-active behaviour, and recorded tide height approximately every 15 minutes. The theodolite operator located the position of the whale during the surfacing. Events recorded by the computer operator included: breath, breach, fluke slap, pectoral fin slap, dorsal fin slap, unidentified splash, porpoising and spy-hop (Ford *et al.*, 2000). The computer was linked to the theodolite to record the time that it retrieved the horizontal and vertical angle co-ordinates of a whale's position. After approximately 15 minutes of no-boat, control observations, the computer operator requested (via VHF radio) that the experimental boat operator approach the focal animal.

Local whalewatch operators agreed to stay well clear (> 1 n.mile) of the focal animals while whale behaviour was recorded under control, no-boat conditions. The experimental boat was a 5.2m rigid-hull *Zodiac* inflatable

with a 90hp Mercury 2-stroke outboard engine. The boat operator was instructed to approach the focal whale slowly, from the side, and then run a course parallel to the whale at approximately 100m. THEOPROG was customised to display the distance between the last two positions as they were collected. After approximately 5-10 minutes, the computer operator asked the boat operator to speed up to overtake the whale. When the distance between boat and whale reached approximately 200m (ahead and to the side of the whale), the boat operator placed the boat directly in the whale's predicted path (completing the leapfrogging manoeuvre). Once the boat was in position, the operator shifted the engine into neutral and left the engine idling as the whale swam past. The boat operator made no sudden direction changes, and was in frequent VHF radio contact with the cliff-based observers. When the whale had swum approximately 500m past the experimental boat, the process was repeated twice more. After the third leapfrog, the operator shut off the engine when the whale was approximately 500m from the boat. The entire treatment period lasted approximately 20 minutes, depending on the whale's swimming speed.

Acoustic monitoring of the experimental vessel

The source and received levels and frequency spectra were calculated from DAT recordings made of the experimental boat under slow (i.e. paralleling speed) and fast (i.e. leapfrogging speed) conditions. A 2m, 15-element calibrated hydrophone array and on-board recording system, both flat to 24kHz, was towed from a recording boat (Miller and Tyack, 1998). The experimental boat operator was instructed to approach the recording boat slowly, at approximately 3kn speed as indicated by a *Magellan 2000XL* handheld GPS. The operator then accelerated towards the recording boat at the throttle position typically used to leapfrog a whale's position. As the experimental boat approached the recording boat, parallel to the hydrophone array, the recorders measured distance to the experimental boat using *Bushnell* laser rangefinders. When the distance reached 100m, a 2s sample of the recording was digitised for subsequent spectral analyses.

Data compilation

A mean dive time (i.e. average time between surfacings) was calculated for each track. The average swimming speed of the whale was obtained by dividing the total distance travelled by the duration of the tracking session. Two measures of path predictability were calculated: a 'directness index' and a 'deviation index' (Fig. 2; Williams *et al.*, 2002).

The directness index is 100 times the ratio of the distance between beginning- and end-points of a path to the cumulative surface distance covered by all dives. It is the inverse of the milling index of Tyack (1982) and Kruse (1991) and ranges from zero (a circular path) to 100 (a straight line).

The deviation index is the mean of all angles between adjacent dives, and can be considered an inverse measure of a path's smoothness. For each surfacing in a track, the angle was calculated between the path taken by a dive and the straight-line path predicted by the dive before it (Williams *et al.*, 2002). The deviation index is the mean of the absolute value of each of these discrepancies, in degrees, during the entire track. A low deviation index indicates a smooth path, while a high deviation index indicates an erratic path. Indices

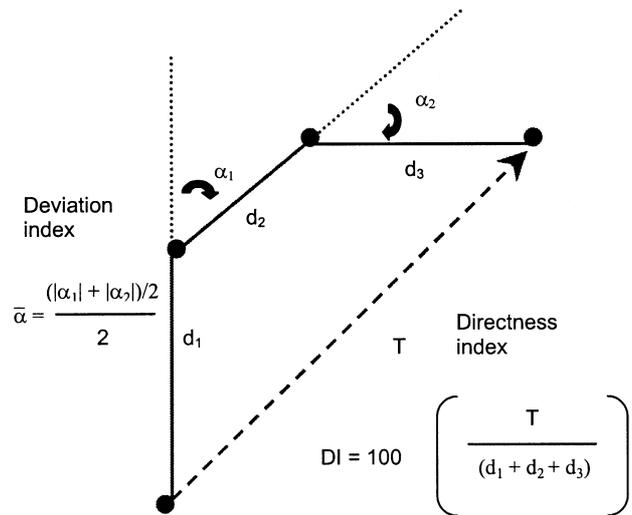


Fig. 2. A sample swimming path with four surfacings (●) and three dives (d_i), showing two measures of path predictability: deviation and directness. The deviation index is the mean of all angles between observed dives and the straight-line paths predicted (---) by preceding dives. The directness index is 100 times the ratio of the track diameter (T) to its perimeter.

of directness and deviation were calculated for each track. A track that shows high deviation and high directness is erratic but directional, whereas a track with low deviation and low directness is smooth but non-directional.

A record was taken each time surface-active events such as spy-hopping or breaching took place. A bout of tail-or fin-slapping was scored as one event if more than one slap took place during a surfacing.

Data analysis

Mean values for each dependent variable were averaged across all observations for an individual, such that each whale was represented only once. Variables recorded under control and experimental conditions were compared using two-tailed, paired *t*-tests. Comparisons were made only when at least 20 minutes of baseline, control observation was followed by an experimental approach of the same whale lasting at least 20 minutes.

RESULTS

Behavioural responses of killer whales to leapfrogging vessel

A total of 12 paired (control-treatment) observations were made of 10 male killer whales (Table 1). Earlier work (Williams *et al.*, 2002) has demonstrated the potential for sex-based differences in boat-avoidance tactics, if not boat tolerance. Consequently, two experimental approaches of female killer whales were excluded from the analyses. Whales responded to a leapfrogging vessel by adopting a path that was significantly less direct ($t_9 = 3.41$, $p = 0.007$), and the mean angle between successive surfacings became significantly greater ($t_9 = -5.29$, $p = 0.001$) than during the preceding, control period (Fig. 3). No significant difference was observed between whale behaviour during control and leapfrog conditions in terms of mean dive time ($t_9 = 0.42$, $p = 0.684$), swim speed ($t_9 = 0.29$, $p = 0.775$) or rate of surface-active behaviour ($t_9 = -1.76$, $p = 0.113$). However,

the power of these tests is low because of the small sample size. Beta probabilities (the probability of accepting a false null hypothesis) were high in the last three trials ($\beta = 0.941, 0.944$ and 0.568 , respectively). This suggests that if these mean and standard deviations were the true values, sample sizes of 1,408, 1,978 and 33, respectively, would be needed to conclude that the differences were significant.

Experimental boat noise

As the experimental boat approached the recording boat at slow speed, the theodolite tracking crew recorded its position 10 times along its path. Mean speed was 5.2km/h (± 1.02 SE). This agrees roughly with the 3kn (5.6km/h) average speed as measured by the GPS. During the high-speed approach, the theodolite team recorded 16 positions, and the measured boat's speed was 23.3km/h (± 1.79 SE). Again, this is corroborated by the simultaneous GPS measure of 12-13kn (22.2-24.1km/h).

Table 1

Number of pairs of observations (control vs. treatment) for each subject. Values were averaged for animals that were approached twice, such that each subject was represented only once in our analyses. Subjects' ages calculated from presumed year of birth reported by Ford *et al* (2000).

Whale	Sub-pod	Tracks	Age
A13	A11	1	20
A33	A12	2	27
A39	A30	1	23
A46	A36	1	17
A6	A30	1	34
B10	B7	1	19
B2	B7	1	≥ 46
B8	B7	1	34
C9	C6	1	27
I41	I15	2	18

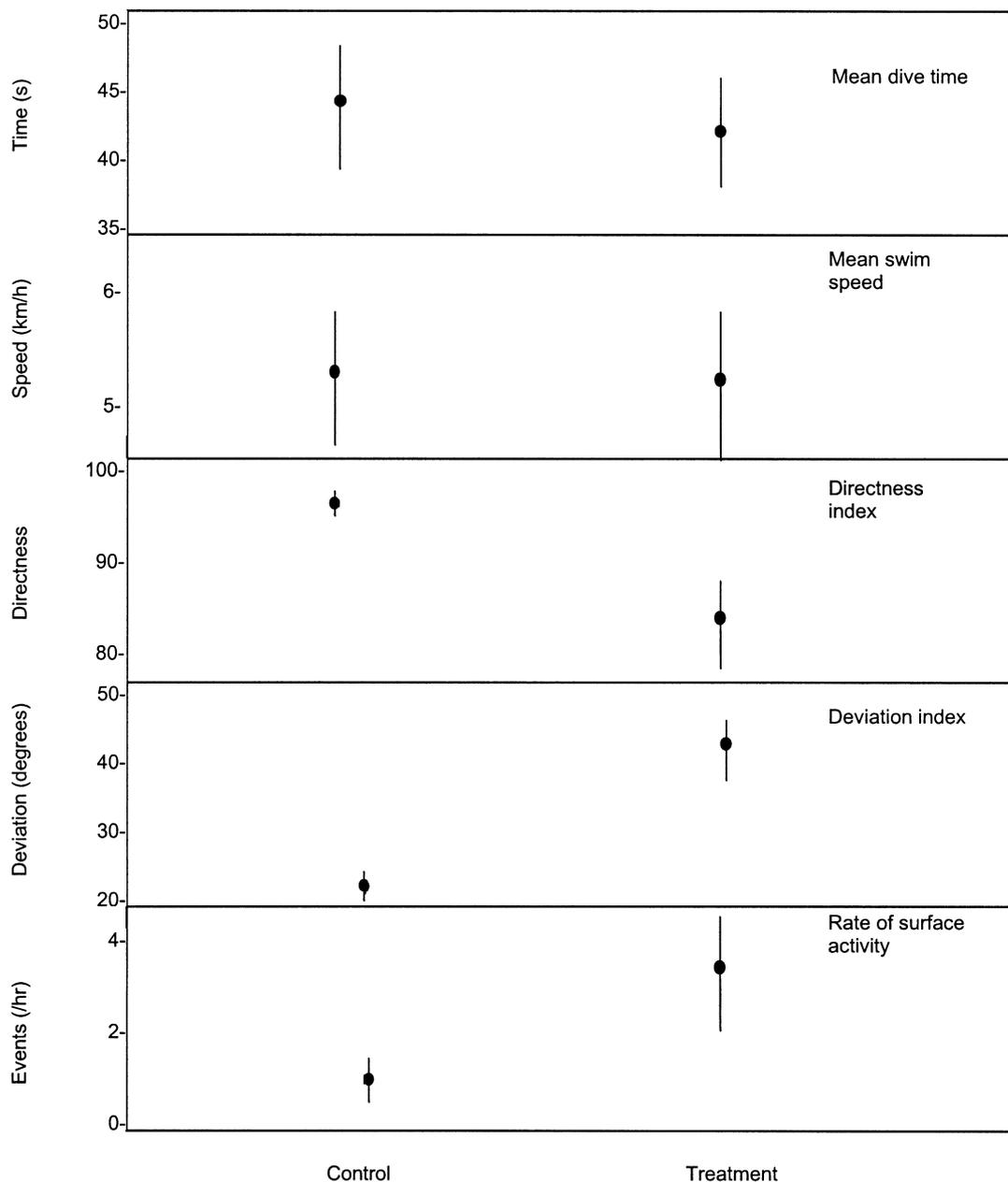


Fig. 3. Behavioural responses (mean \pm SE) of whales to experimental approach by a leapfrogging vessel.

The mean speed of the experimental boat was measured during the leapfrogging sections of the theodolite tracks. On average, the experimental boat sped up to 20.7km/h (± 1.70 SE) during the leapfrog components of the 12 treatment tracks. The recordings made of the experimental boat during the high-speed approach are thought to accurately represent sound production during leapfrog approaches of whales: the mean speed of the boat did not differ significantly between samples ($t_{25} = -0.99, p = 0.330$).

Source level of the experimental boat at slow speed was estimated to be 148dB *re*: 1 μ Pa at 1m, assuming a spherical transmission loss model (Richardson *et al.*, 1995). When the experimental boat sped up to leapfrog, the source level increased to 162dB *re*: 1 μ Pa at 1m – an overall difference of +14dB. The greater sound pressure level under high speed was found across the entire frequency range of the on-board multi-channel recording equipment, and was observable to at least 24kHz (Fig. 4). The received levels were measured at 100m, and are presented in Fig. 4. At 200m, the distance at which the boat operator was instructed to leapfrog the whale's position, the received level was approximately 116dB.

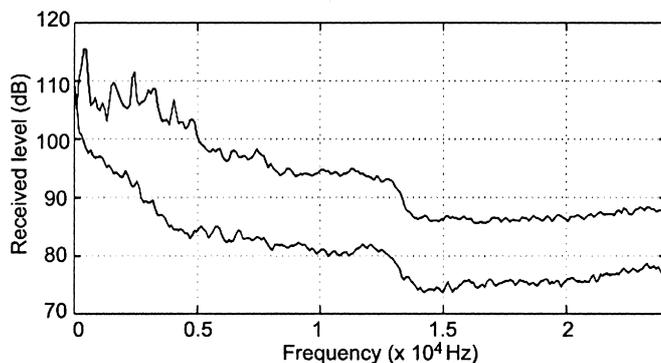


Fig. 4. Power spectral density comparing relative received noise level 100m from the experimental boat under fast (upper line) and slow (lower line) operating speeds.

If it is assumed that sound levels drop at $20\log_{10}(\text{range})$, a leapfrogging boat would need to be approximately 500m away from the whale for the level received by the whale to be the same as that from a boat paralleling at slow speed at 100m (Richardson *et al.*, 1995).

DISCUSSION

Northern resident killer whales evaded the leapfrogging vessel on two spatial scales (deviation and direction). Increased deviation index reflected a less predictable path on the scale of one surfacing to the next, while the reduced directness index reflected a less predictable path on the scale of an entire 20 minute observation session. These path predictability parameters were the same ones altered by a boat following whalewatching guidelines (Williams *et al.*, 2002), and therefore could be useful indices for assessing disturbance in northern resident killer whales.

There was a pronounced difference in the quality and level of sound produced by the experimental boat operating under two speeds. It is strongly recommended that whalewatching guidelines, in addition to limiting leapfrogging and proximity, also address speed of vessels around whales. In the absence of experimental studies to guide whalewatching activity by regulating noise level received by killer whales,

reducing boat speed is a useful proxy (Richardson *et al.*, 1995). More specifically, boaters should be discouraged from operating outboard engines at full speed within 500m of whales.

These findings are especially interesting in view of recent attempts to model zones of influence from boat noise (Erbe, 2002). The results in this paper are consistent with Erbe's prediction that a fast-moving boat would elicit change in behaviour of killer whales at 200-250m. Her prediction was based on the assumption that a 120dB received level would cause behavioural change in 50% of cetaceans (Richardson *et al.*, 1995). In fact, the current study demonstrated significant behavioural responses of male resident killer whales at received levels of approximately 116dB.

Effective management of whalewatching often requires choosing between practices that maximise human benefit and those that minimise disturbance to whales (Duffus and Dearden, 1993). The gain to whalewatchers from leapfrogging, where the benefit is a closer approach than that offered by other styles of whalewatching, may not be as high as one might assume. One study in Australia tested the assumption that whalewatchers wish to get close to whales (Orams, 2000), and found that tourist satisfaction was influenced by the number and behaviour of humpback whales, numbers of fellow passengers, cruise duration, boat construction and seasickness. However, proximity of the whales was not a major influence. The tendency in Johnstone Strait to discourage leapfrogging may be a case where mitigating disturbance to whales costs whalewatch operators very little in terms of tourist satisfaction.

Leapfrogging in close proximity to whales is a style of whalewatching engaged in mostly by the boating public, rather than by commercial operators in Johnstone Strait. Thus, the sample size in the present experiment was intended to test the null hypothesis that leapfrogging has no effect on behaviour. This sample was not intended to be large enough for the more stringent test of whether leapfrogging had more effect than paralleling, since this was not a particularly urgent management goal in Johnstone Strait, although it might be of interest to managers in other areas.

It is unfortunate that the experimental boat that elicited behavioural responses to a paralleling vessel at 100m in 1995 and 1996 (Williams *et al.*, 2002) is no longer available for acoustic monitoring. A concerted, experimental study to test both treatments simultaneously on the same subjects would be required. The members of the whalewatching and research communities of Johnstone Strait aim to endorse and follow biologically relevant whalewatching guidelines. It may be sufficient for their purposes to demonstrate that leapfrogging is disruptive. It is not necessary to illustrate that one whalewatching tactic is more disturbing to whales than another (given the same vessel and focal animals). Nonetheless, a qualitative comparison of whales' behavioural responses to the two types of whalewatching, paralleling and leapfrogging, may be instructive.

When a single vessel approached northern resident killer whales in 1995 and 1996 to parallel the animals at 100m, mean directness index of male killer whales declined from 83.6 to 74.1. A directness index of 83.6 is equivalent to having to travel 119.6m along a circuitous path to gain 100m of headway. The decline in directness index while a boat parallels at 100m is equivalent to having to travel 135m to cover the same distance – an increase of 13%. During leapfrogging tracks, mean directness index declined from 94.1 to 80.5, an increase of 17% in the distance a whale would have to swim to cover 100m of straight-line distance. More telling is the fact that no significant change was noted

in the deviation index, the mean angle between surfacings, when the experimental boat paralleled male whales' paths at 100m ($t_{23} = 0.56, p = 0.58$) (Williams *et al.*, 2002). When the experimental boat leapfrogged the swimming paths of the whales, the animals increased the mean angle between successive surfacings by 90%, from 20.4° to 38.7° (Fig. 3). A particularly noteworthy aspect of these findings was that significant effects were apparent even with small sample sizes.

Studies that measure short-term responses of animals to human disturbance often stem from an inability to tackle directly the underlying concern that repeated disturbance may have a cumulative impact on wildlife populations. Northern resident killer whales continue to return to Johnstone Strait each year after more than 20 years of whalewatching traffic and the population increased throughout this period (Ford *et al.*, 2000). Nevertheless, whalewatching has been cited as a likely contributing factor in recent population declines of southern resident killer whales (Baird, 2001).

Bain *et al.* (2002) produced a model for extrapolating energetic consequences, including those addressed in this study, to population-level effects. Studies employing methods similar to those here may be useful in quantifying the nature and magnitude of avoidance responses in order to estimate potential population-level costs of whalewatching across a range of traffic levels. More importantly, this work reveals an opportunity to mitigate some impact. By identifying a whalewatching practice that certainly carries energetic costs for killer whales and may reduce their foraging efficiency, it is hoped that members of the Johnstone Strait community continue to discourage that practice. Likewise, it is hoped that resource managers in other areas are encouraged by the Johnstone Strait model of establishing reasonable guidelines proactively, and then testing those guidelines experimentally to ensure biological relevance. Reducing short-term effects may ensure ultimately the mitigation of long-term consequences.

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